Early Journal Content on JSTOR, Free to Anyone in the World

This article is one of nearly 500,000 scholarly works digitized and made freely available to everyone in the world by JSTOR.

Known as the Early Journal Content, this set of works include research articles, news, letters, and other writings published in more than 200 of the oldest leading academic journals. The works date from the mid-seventeenth to the early twentieth centuries.

We encourage people to read and share the Early Journal Content openly and to tell others that this resource exists. People may post this content online or redistribute in any way for non-commercial purposes.

Read more about Early Journal Content at http://about.jstor.org/participate-jstor/individuals/early-journal-content.

JSTOR is a digital library of academic journals, books, and primary source objects. JSTOR helps people discover, use, and build upon a wide range of content through a powerful research and teaching platform, and preserves this content for future generations. JSTOR is part of ITHAKA, a not-for-profit organization that also includes Ithaka S+R and Portico. For more information about JSTOR, please contact support@jstor.org.

THE FORMATION OF RIPPLE-MARKS, TRACKS, AND TRAILS.

BY AMOS P. BROWN, PH.D.

In the summer of 1902 I spent a portion of August in camp near the head of Sandwich Bay, Labrador. Our camp was located at a place called Dove Point on the charts, near the mouth of Dove Brook and at the mouth of the estuary of White Bear River, which latter empties into this arm of the bay some three miles above the Point. Dove Point extends out from the north shore of Sandwich Bay for more than a mile, nearly to the channel leading to the river mouth, the deep-water portion of which is here about one-third of a mile wide. Extending to the northeast, towards Dove Brook and the Mealy Mountains, are wide mud flats, laid bare with each low tide; beginning with a breadth of a mile and a half at the Point and gradually narrowing until they disappear altogether at some 4 or 5 miles along the shore. To the northwest of the Point they extend for some three miles, beginning with a width of half a mile and gradually narrowing to the mouth of White Bear River.

The higher ground at the Point, about 20 feet above the water level, is composed of sand and gravel with occasional boulders, which probably represents the *Saxicava* sands or Upper Boulder deposits of Canada, although no fossils were found in the sands. At their base and underlying these sands is the clay deposit, in which is found numerous shells of the *Leda* clays, such as *Saxicava arctica* Desh., *Serripes groenlandicus* (Chem.), *Astarte elliptica* McGill, *Macoma sabulosa* Mörch, etc., and scattered over the surface of the clay flats are many large boulders left by the erosion of the clays by the water. As the tide is not very high here, about three feet on the average, these flats are gradually covered by a shallow layer of water, which ripples in over the flat with each rising tide. It is generally accompanied by wind, which makes little wavelets that break on the shore when the water finally reaches it. The level of the flats is so nearly perfect that when they are completely covered by the rising tide this layer of water is in general but a few inches deep near the shore, though at some distance from the shore it may be three feet deep over some parts of the flat that were laid bare at low tide. The clay is particularly firm and compact, and retains impressions made upon it for many succeeding tides. As the bay freezes to the bottom

in winter, even down to a much greater depth than is exposed by the receding tide, the firm character of the clay may be due in part to the effect of ice pressure, but this clay deposit was doubtless covered by the sand and gravel of which a remnant remains in the raised ground on the Point, and this being some 20 feet thick would have compressed the clay to the firmness which it exhibited upon these flats. To the northwest of our camp it was beautifully rippled for a mile or more and for the full width of the flats. The sandy strand on the west side of Dove Point was also rippled with each tide. I thus had an excellent opportunity to study the formation of *water-formed* ripple-marks and other impressions made upon this clay surface, and I was at once struck by their close resemblance to similar markings so common in the continental deposits of the Triassic of the State of Pennsylvania, which I had studied while connected with the Geological Survey of that State. Other markings on these clay surfaces closely resembled the tracks and trails described and figured by Hitchcock in the rocks of this age in the Connecticut Valley.[1] Their origin on these mud flats could readily be seen and, as they so exactly resemble the formations found in the rocks, a description of them may throw some light upon the markings observed by Hitchcock and others.

No living mollusks were seen on the mud flats, being doubtless killed by the freezing of the bay in winter, but species of *Mya* are evidently living in the deeper water of the bay, as their shells were occasionally encountered in places where they had been stranded by the tide. To the east, towards the Mealy Mountains along the shore, a few specimens of gastropods were seen, some three or four miles down the bay.

While mollusks are rare, the sea weeds in some parts of the bay flourish in great luxuriance. Where the shore is rocky and the bottom is composed of sand and shingle rather than clay, as is the case to the east side of the bay, especially from East Arm to Cartwright, and, in fact, along all the shores examined where the conditions were favorable, the bottom is covered with a dense growth of *Fucus*, probably *F. vesciculosus* L., which here attains a height of three or four feet and forms dense masses of several feet in diameter. In the deeper water, especially in the channels, are seen the broad fronds of *Laminaria longicrucis* De la Pyl., extending up from the bottom and the laminæ waving about in the current. When seen

[1] Edward Hitchcock, *Ichnology of New England*, 1858; *Supplement to the Ichnology of New England*, 1865.

stranded on the shore, the fronds are found to be twenty or twenty-five feet long or even more, including six or eight feet of stipe. Along the rocky shores everywhere towards the head of the bay, and even on the clay flats, attached to stones and pebbles, the *Ulva enteromorpha* Le Jolis was seen growing abundantly. When I add that the shores of the point were covered with pieces of drift wood of all sizes so thickly that we were not in need of other fuel for our camp during our stay there, and that various species of ducks, snipe and other water birds frequently traversed the surface, while occasional bear and caribou came close up to our camp across the flats, I have

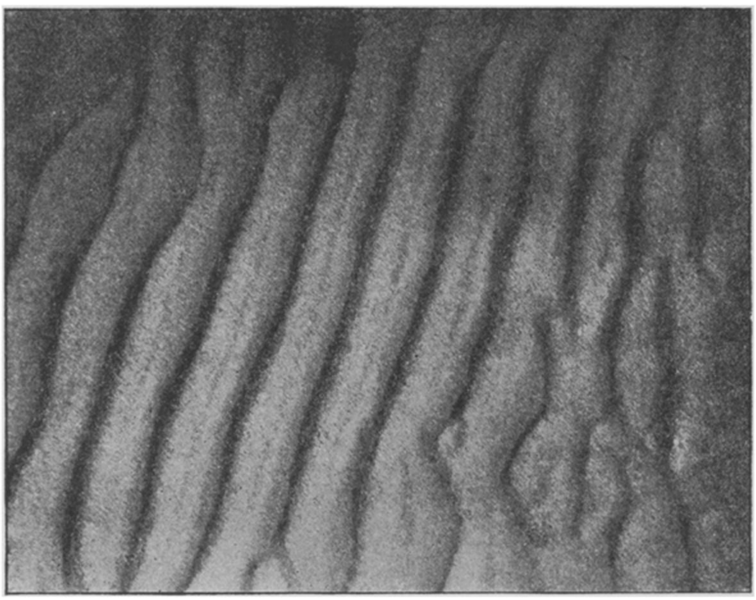

Fig. 1.—Ripples of deposition.

enumerated nearly all the factors concerned in the formation of the markings noted.

The Ripple-marks.—The study of recent ripple-marks seems to have been largely confined to wind ripples on sandy surfaces and to current ripples in channels and along the shore. A study of these ripples formed along the strand and on the clay flats at Dove Point discloses at once the fact that they are of two kinds; and these two kinds are formed at the sandy strand and on the clay flats, respectively. They are, on the shore, ripples of *deposition* (mainly), and on the clay flats they are ripples of *erosion*.

The sandy strand was always ripple-marked after each tide, if the surface of the water in the bay was somewhat ruffled by the wind. The incoming tide pushed the sand along and, combined with the wave motion in the shallow water, moulded the sandy surface into a series of ripples which closely resemble those made by the wind on dry, sandy surfaces. They are mainly ripples of deposition, the sand surface moving with the advancing water as the dry sand surface, thrown into wind ripples, advances under the force of the wind. But there is also a little erosion in the shaping of these ripples, although the main action of the water is to deposit material.

The sand ripples which form along the strand are quite large; they range from three to four inches from crest to crest, and sometimes are even wider. The depth of the trough is $\frac{3}{4}$ inch or more in some cases. Their general appearance is well shown in fig. 1, which is a photograph of this rippled surface taken looking vertically down

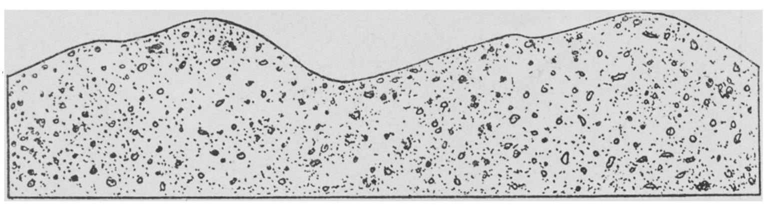

Fig. 2.—Section of ripples of deposition.

from above. Here the left of the picture is that portion of the strand towards the open water of the bay and the right is towards the land. When the tide is coming in the water and sand transported by it are moving from the bay towards the land. The slope of the ripple towards the water or bay side is gentle; up this slope the advancing water pushes the sand grains, which, after they pass the crest, fall down the steeper landward slope of the ripple and assume the angle of repose, making the ripple steeper on this landward side. The advancing water strikes the bay slope of the next ripple and removes a portion of its surface, from the fainter, smaller crest seen on this slope in the photograph up to the crest itself. The result is that the landward slope continually advances, while parts are cut away from the bay-side slope so that the one grows by deposition of the material removed from the other. The top of the ripple is rounded with one steep side, sloping down to a rather sharp trough, and one gently sloping side, running from this trough

to the next crest, and this gentle slope having its upper part continually cut away by the water action, making a little subsidiary ripple-mark (fig. 2). During the advance of the tide these ripple-marks are formed over large strand surfaces, and when the tide recedes they are often modifed and the troughs deepened by erosion. In some cases they are obliterated, in other cases they may be covered up by other sand deposits and preserved; but in general this last will only happen occasionally, when an exceptionally high tide or a flood from a river brings down an unusual amount of material from

Fig. 3.—View of rippled strand.

the shore. As the streams here are mostly bog-fed, this can only happen by landslide or other cause that adds a large amount of detritus to the stream water. At Dove Point the ripples in the sand of the strand could hardly be preserved, except in case of very high tide. This double form of ripple of *deposition* is found in wind-swept sand also, but does not seem to be very common among the ripple-marked surfaces that are preserved in the rocks. It is quite probable that the bulk of these are produced by erosion alone, not by deposition, and the ripples made by erosion are of a different form.

Where these strand ripples of deposition are reworked by the receding tide they are deepened in the trough, the steep side becomes rather steeper and the crest crumbles away, becoming sometimes narrower, sometimes even sinking locally by the softening and collapse of the sand when impregnated with water. The waves in the water undoubtedly condition the formation of the ripples in the sand. In fig. 3 the rippled strand is shown after the tide has partly receded and the small water waves seen on the surface of the bay are similar to those that have rippled the sandy shore. The sands here are derived from the raised beach of the *Saxicava* sands, which formation is formed on both sides of the estuary of White Bear River. They are being continually washed down from the banks of this raised beach upon the *Leda* clays, which they overlie stratigraphically.

The clays of the flats are finely rippled in some places over large surfaces. The appearance of these rippled surfaces is well shown

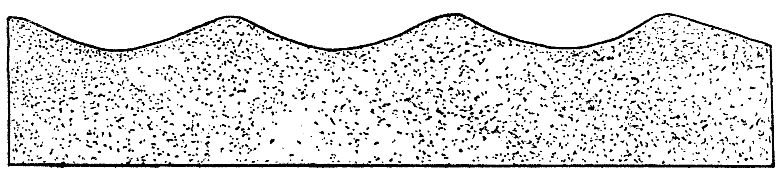

Fig. 4.—Section of ripples of erosion.

in the photograph, Plate XLI, fig. 1, which was taken on the flats about one-quarter of a mile to the west of our camp. The boulder-strewn surface of the flat is very noticeable at the back of the picture. These ripples were carved out of the hard, tough surface of the *Leda* clay, and were so firm that in walking over them in the Eskimo skin boots we wore we left scarcely any impression; and even a bear, traversing this ripple-marked surface, did not flatten down the crests of the ripples very much. They were quite uniform in dimensions, as the picture shows, with a width from crest to crest of the ripples of about one and three-quarters to two inches and a depth amounting to not more than one-quarter of an inch. Unlike the ripples of deposition, these erosion ripples had a rather sharp crest, about one-quarter of an inch broad; the trough was concave, nearly or quite symmetrically so, and rounded out with a gentle curve (see fig. 4). They did not cover the entire surface of the flat, but were more pronounced where the water had to travel a greater distance over the flat, and where, therefore, there was more current.

As the tide rose continuously, and the water advanced regularly over the flat, there was a progressive flow of the water over the surface of the mud; but, in some places, ripples were regularly produced; in other places, especially near the shore, the surface was nearly plane and free of ripples, Plate XLI, fig. 2. On these surfaces other markings were produced. The rippling of the water by the winds is the cause of the formation of these erosion ripples. Their formation was investigated by wading about in the shallow water, two to six inches deep, while the tide was advancing over the flats. It was then seen that at the passage of each wave there was raised a slight cloud of muddy water from the concave of the ripple. The surface of the clay was softened for about one or two millimeters in depth when the tide was in over the flats, and in this soft surface impressions could be made by any object moving over the bottom and touching it, from time to time or continuously. But the ripples were very permanent, remaining in the same place for days. That they have the origin assigned to them there can be no doubt, they are not of the form of the ripples of deposition and they are firm and persistent. They closely resemble the ordinary forms of ripples that are seen on the rock surfaces in the Trias, for example; and that erosion was the source of these Triassic ripples in many cases, I have very little doubt. They are very constant in form, as has been noted, and very persistent, owing to the tough and tenacious character of the *Leda* clay. That such ripple-marked surfaces should be preserved if the flats were subject to inundations by water highly charged with sediment seems certain; and while such was not the case here, the water would be just as efficient as an erosive agent if it contained a charge of sediment. The wind waves start the erosion of the ripple; but, as it develops, it reacts upon the water, producing waves when the wind is not blowing as well as when the surface of the water is rippled by the wind. That this form of erosion ripples is more common on hard mud bottoms than the ripple of deposition and that on sandy bottoms the ripple produced by deposition is more common, is indicated, too, by an examination of rippled surfaces of rock. The finer material seems to be more often marked with the symmetrically concave, sharp crested, erosion ripples; while the coarser materials, such as sands, show more often the rounded crest and peculiar unsymmetrical shape of the deposition ripples.

The Tracks of Animals.—As has been noted above, large mammals and birds, moving over the clay flats, left their foot-marks upon the

surfaces. On one occasion a caribou almost walked into camp during the early morning and it traversed about two miles of the flat to the west. Its foot-prints were deeply impressed into the clay surface; on the rippled parts they were more than the depth of the ripple-mark. The median digits were impressed below the level of the trough of the ripple, and even the lateral digits sometimes made a mark, especially where the foot had slipped slightly. The clay was so firm, however, that the foot-prints did not exceed one inch in depth at any place, although this deer is a heavy animal. The impressions were very persistent, they continued to be distinctly outlined for days after they had been formed; and, indeed, were quite distinguishable when we left the camp, about a week after they had been impressed in the clay. They probably lasted much longer, yet they were covered by the tide twice in each twenty-four hours during the period of observation. If this water had contained any considerable amount of sediment they might have been covered and preserved.

At another time one or two bears were roaming about on the flats; they left a much less distinct impression, scarcely flattening out the ripples in the clay, though in some cases their claws were deeply impressed. This indicates the hard character of the clay, for these animals have considerable weight. Being plantigrade, the larger surface distributes the weight, so that the foot-prints were not deeply impressed. Nevertheless, they could be traced after the flats had been covered by several succeeding tides, and the claw portion of the track was visible after 5 or 6 tides.

Some dogs (temporarily abandoned by their owners, who had gone out to the coast to fish during the summer) attached themselves to our camp; and their tracks, made when they were coming in for their meals, were also found to last for two or three days. Our own tracks were about as permanent, unless in the softened clay, where they were of course more deeply impressed and therefore much more permanent. The tracks made by the birds only affected the shallow layer of soft clay, perhaps about one-eighth of an inch deep, and they generally could not be seen after one tide had covered them. In some of the unrippled places, however, the bird tracks seemed to be covered by clay, and were doubtless preserved until the surface was again eroded. Of course, if much sediment were being deposited, they might be preserved permanently, but here they were generally only temporary.

These animal tracks, when deeply impressed into the clay surface,

could all be permanently preserved in places where the rivers are bringing considerable sediment into the water; where the flats are less frequently covered by the water, as, for instance, in the case of the flood plains in the estuary of a river, they would have more chance to be permanently preserved. From observations made elsewhere, where a river that was subject to freshets after heavy rains covered such flood grounds, the sediment after one rise would often amount to one-quarter of an inch of silt, which would dry to about one-third of this thickness. Such a layer would be quite enough to cover and preserve all but the deeper tracks; and even these might be filled in some cases. But the permanence and sharply defined character of the impressions were the most significant facts observed at this locality.

The Trails and other Impressions on the Clay Flats.—In his "Ichnology of New England," 1858, and the "Supplement to the Ichnology of New England," 1865, Edward Hitchcock has described, besides undoubted reptilian and batrachian tracks, many other markings which he observed on the shale and sandstone layers of the Connecticut Triassic. Some of them he ascribes to fishes, Crustaceans, Annelids, and insects, as well as some which he calls "fucoids," or simply "plants," and a few that he did not assign to any group. The illustrations of these irregular markings ascribed to fishes, such as his genus *Ptilichnus*, as well as some that he calls "of doubtful character," such as his *Grammichnus* and *Ænigmichnus*, and some of the "crustacean" and "insect" tracks, are very much like forms that I observed on some of the smoother parts of these flats. Continuous trails, such as he calls annelid tracks, were also common, and in all cases the manner of production of these trails was observed. They were not here produced by living animals in any case. For instance, when the incoming tide carried along with it a bunch of *Ulva enteromorpha* attached to a small gravel stone, it might make a continuous line in the clay, as shown in Plate XLII. This line would take any direction, depending upon the eddies in the water; it would even double upon itself and the tracks would cross. When the tide was receding the movements were often more linear and the trails left were much straighter. Those photographed were obtained after the tide had receded and the bunches were left stranded. The *Ulva enteromorpha* grows in tufts of some six to eight inches high, attached to stones and pebbles which serve to anchor it. As the plant increases in size, the flotation of the bushy fronds becomes, in moving water, sufficiently strong to

move the small pebbles, up to three-quarters of an inch in diameter, for instance. Where these are caught by the incoming tide they are carried along in the water at a rate that depends upon the drag of the anchor. Observations were made upon them in water varying from six to ten inches deep, by wading out on the flats from the shore, and in deeper water by observing the motion from a boat. The fronds of the *Ulva* stood upright from the anchoring pebble and waved back and forth with the passage of the wind waves. But as the fronds are exceedingly flexuous, the anchor was not lifted from the bottom, as a rule, by the passage of a wave; the frond simply expanded and collāpsed, or rose and fell, with the up and down movement of the surface of the water; and as far as the graving action of the pebble was concerned, it was continuous or nearly so. The trails made were more or less deeply impressed according as the muddy surface was more or less yielding, and also according as the anchor was pressing with full force or with a diminished pressure, as the frond of the *Ulva* was extended or collapsed by the movement of the waves. In some cases the trails were made by the advancing plant being dragged towards shore by the incoming tide, in other cases by the receding tide carrying it away from shore.

The form of the trail that was left depended upon the shape of the pebble. Thus some were simply single concave grooves, the sides being raised a little above the general surface of the mud, and these look like what are called molluscan or annelid trails in such structures when found fossil. They are very much like Hitchcock's *Unisulcus.* Others were double grooves, when the shape of the anchoring pebble was more irregular or when it had a groove in its lower side. These were like Hitchcock's *Bisulcus.* It should be borne in mind that the *Ulva* is attached to one point on the anchoring pebble, and hence that one side of the pebble is *always* uppermost, so that the surface which makes the impressions is always the same one.

Hitchcock's genus *Ptilichnus* is represented by a track which consists of a very irregular series of markings that recur at regular intervals, but that could not be made by the feet or other appendages of passing animals. He assigns them to markings made by fishes. Of these tracks he describes several species, distinguished by the varying forms of the tracks. Such are *Ptilichnus anomalus*, *P. pectinatus*, *P. hydrodromus*, etc. Another such track is what Hitchcock calls *Saltator*, under the impression that the regularly recurring impressions were made by some leaping animal. All of these,

which will be found figured in the "Ichnology," are very similar to the trails left by a piece of seaweed rolled along the bottom by the advancing or receding tide. I watched this movement of tufts of *Fucus vesciculosus* L., many times and the impressions formed certainly bear a very close resemblance to many of the forms described and figured by Hitchcock.

These tufts are the ends of fronds, pieces varying from four or five inches up to eight or ten inches in length, more or less conical in general outline and in all cases broader at the outer end of the frond than at the stem end. The advancing tide rolls them over and over, generally more or less in a curved line, due to the somewhat conical or pear shape of the tuft. The stem end thus touches from time to time and makes a series of irregular impressions, somewhat removed from the main line of impressions of the fruiting ends of the frond. The marks made by the stem are deeper, but smaller than those made by the fruiting terminations of the branches These fruiting tips of the branches are bifid or trifid as well as simple, conical, bladder-like expansions and they sometimes make impressions that simulate the tracks of three-toed reptiles or other animal tracks. They look, however, as though only one foot were touching, as they all point in one way. In the more globular tufts of the weed the rolling motion is more irregular and the stem does not always point in one direction, but the bunch may turn over, end for end, occasionally; then the arrangement of the series of impressions formed will often suddenly reverse right and left. In nearly all cases where these impressions were seen they were observed under water only, the weed drifting in from the channel off Dove Point, and hence no photographs were obtained. Hitchcock's *Ptilichnus anomalus* trails, as well as most of the impressions that he calls *Ænigmichnus multiformis*, probably had some such origin as that indicated above.

A small branching twig of, say, a spruce or cedar would make a trail like the *Saltator* impression which he describes, if it were rolling over and over on the bottom under the influence of the advancing or receding tide. A piece of a branch or a trunk, without notable projections, being advanced along the bottom by rolling under the influence of the rising tide, would make an impression like Hitchcock's figure of *Ænigmichnus multiformis* given on Plate XIV of the "Supplement to the Ichnology of New England." This slab was $3\frac{1}{2}$ feet by $4\frac{1}{2}$ feet. The slab is crossed by "numerous rows of impressions, certainly not less than thirty-five, the impressions are circular as

though made by a punch, or they are elongated or even linear." There are also "linear furrows nearly parallel to the other impressions, but crossing at a small angle," which were made, no doubt, by some other object subsequently, perhaps during a different tide.

He also describes another slab with *Ænigmichnus* on which were "a trifid arrangement of somewhat triangular toes with two dents behind and two or three on one side, and this arrangement is repeated about once in an inch. The axis of the foot in this case is turned aside from the line of direction as much as 30°, but I cannot decide in which direction the animal was moving nor find a series of impressions to the right or left corresponding to this one."

This description (and the figure on Plate I, "Supplement") represent very exactly the kind of impressions made by a rolling piece of *Fucus*. Thus only the feet on one side of the hypothetical animal make any impression, or else it must move sidewise, but the impressions recur at perfectly regular intervals. That is exactly the character of impressions made by an object rolling over the bottom, and it is also the character of the impressions made by the rollers in a print mill manufacturing cotton prints. That the "foot-marks" were all *right* or all *left* might have suggested this analogy, if the idea of a rolling object had occurred to Prof. Hitchcock.

From the foregoing, it is evident that markings closely simulating molluscan and annelid trails *may* be produced without animal agency, and even such markings as may be mistaken for those made by fishes, crustaceans or reptiles may be similarly produced.

Explanation of Plates XLI and XLII.

Plate XLI.—Fig. 1.—Rippled surfaces of the *Leda* clay on the flats northwest of Dove Point, looking westward.

Fig. 2.—A nearer view of the erosion ripples on the clay flats, looking east towards Dove Point.

Plate XLII.—Fig. 1.—Trail made by a pebble attached to a tuft of *Ulva enteromorpha*, and dragged over the bottom. The attached tuft of the *Ulva* may be seen in a collapsed condition at the end of the trail.

Fig. 2.—A part of the clay flats, covered with pebbles with their attached *Ulva* tufts, that have left markings by their movement over the bottom.

Fig. 3.—A portion of fig. 2, enlarged, showing some of the markings in more detail.

1

2

A. P. BROWN: RIPPLE-MARKS, TRACKS AND TRAILS.

1

2

3

A. P. BROWN: RIPPLE-MARKS, TRACKS AND TRAILS.